

The multilayer device **240** provides cumulative stiffness and damping control of the individual polymer layers **241**. In one embodiment, electrodes **243** and **244** and their associated control electronics are configured to provide synchronous control for polymers **241**. In another embodiment, electrodes **243** and **244** and their associated control electronics are configured to provide separate control for each polymer **241**. In this manner, one may use simple on/off voltage control to independently provide stiffness control for each polymer **241**. This binary independent on/off control allows a user relatively simple graduated stiffness control for device **240** since the effective stiffness is the sum of the stiffnesses of the individual polymer elements **241**.

Another linear device suitable for use with the present invention was described in FIGS. **4C–4D**. In another embodiment, electroactive polymers suitable for use the present invention may be rolled or folded into linear transducers and devices that deflect axially. As fabrication of electroactive polymers is often simplest with fewer numbers of layers, rolled actuators provide an efficient manner of squeezing large layers of polymer into a compact shape. Rolled or folded transducers and devices typically include two or more layers of polymer. Rolled or folded devices are applicable wherever linear devices are used, such as robotic legs and fingers.

Generally, devices of the present invention comprise a mechanical interface that transfers forces between the polymer and an external load. For example, any one or more of the rigid members **204** of device **200** may be coupled to a vibrating structure. Alternately, any of the rigid members included at the distal end of a linear transducer may be used for external mechanical attachment and interface with a reciprocating rigid member. The external load need not be a solid structure. For example, a mass attached to the center of an electroactive polymer diaphragm may be used as the mechanical interface to transfer mechanical energy between the diaphragm and a fluid source.

#### 11. Multifunctionality

For ease of understanding, the present invention has primarily been described and shown by focusing on a single electroactive polymer function—providing stiffness or damping. However, electroactive polymer transducers have other functional uses such as actuation, generation and sensing. In one aspect, devices of the present invention may be integrated with other electroactive polymer functions. Electroactive polymer transducers and their associated devices configured to have more than one function are referred to herein as ‘multifunctional’.

Some transducers and devices of the present invention may also be configured or designed for use as an actuator to produce mechanical output in addition to providing stiffness and/or damping control. In this case, the transducer is also arranged in a manner which causes a portion of the polymer to deflect in response to a change in electric field provided by the at least two electrodes. Suitable electroactive polymer actuators are further described in Ser. No. 09/619,848, which was previously incorporated by reference. Transducers and devices that provide actuation and stiffness or damping control are well suited for use in macro and micro robotics, for example.

In a specific multifunctional application, higher frequency vibrations may be damped out on a robot arm using filtering, e.g., using the classical description of closed loop systems described above. However, one may also apply co-contraction on a robot arm where two or more actuators exert opposing forces on a single robotic link. This ability to

load, or preload, polymers against each other allows a robotic system to achieve stiffness control by several methods described herein such as stiffness regime or open or closed loop methods.

Another common electroactive polymer transducer function is converting mechanical to electrical energy—or generation. The mechanical energy may be harvested from a mechanical source that is deflecting the polymer, such as a vibrating source. Thus, some systems of the present invention may also be configured or designed for use as a generator to produce electrical energy. Typically, a generator of the present invention comprises a polymer arranged in a manner that causes a change in electric field in response to deflection of a portion of the polymer. The change in electric field, along with changes in the polymer dimension in the direction of the field, produces an increase in voltage, and hence an increase in electrical energy. The increase in electrical energy may be harvested and stored by generation circuitry in electrical communication with the electrodes. Suitable electroactive polymer generator circuits are further described in Ser. No. 09/792,877, which is incorporated herein by reference for all purposes.

Open and closed loop control systems may also include provisions to harvest some of the generated energy in the polymer rather than just dumping it through a resistor. For example, the open loop control can include transformer elements to transform some of the power down to a low voltage suitable for microprocessors and other low voltage IC components. In this case, the device can be self-powered, using a small battery to store and recycle the energy for start-up. In a specific embodiment, an electroactive polymer is configured as a shock absorber (controllable stiffness and damping mechanism) that harvests some of the energy that is absorbed.

As described above, yet another electroactive polymer transducer function is sensing. Thus, transducers of the present invention may be configured to provide variable stiffness and/or damping, actuation to convert from electrical to mechanical energy, generation to convert from mechanical to electrical energy, sensing to detect changes in a parameter, or any combination thereof.

#### 12. Applications

As the present invention includes transducers and systems that may be implemented in both the micro and macro scales, implemented in applications where stiffness and/or damping is desirable, and implemented with a wide variety of designs, the present invention finds use in a broad range of applications. Provided below are several exemplary applications.

Variable stiffness electroactive polymer devices and systems are well-suited for use as noise and vibration controls. For example, noise control depends on minimizing the net volume acceleration of a vibrating surface. Variable stiffness transducers of the present invention may be placed on vibrating surfaces to actively (closed loop) or passively (open loop) resist motion. For closed loop control, the vibration control may comprise repeatedly a) actuating the polymer out of phase from motion of the vibrating surface that causes the polymer to contract, and b) absorbing electrical energy in generator mode out of phase from motion of the vibrating surface that causes the polymer to expand.

Variable stiffness can be used in open loop vibration control. For example, in an engine mount, the engine piston firing frequency is known; thus allowing a device that provides an open loop stiffness that shifts the engine mount resonant frequency to temper oscillations. Similarly for aircraft and turbine blades, the stiffness/damping could be